Advanced Ceramic Matrix Composites with Multifunctional and Hybrid Structures

M. Singh
QSS Group, Inc.
NASA Glenn Research Center
Cleveland, OH 44135

G. N. Morscher
Ohio Aerospace Institute
NASA Glenn Research Center
Cleveland, OH 44135

Abstract

Ceramic matrix composites are leading candidate materials for a number of applications in aeronautics, space, energy, and nuclear industries. Potential composite applications differ in their requirements for thickness. For example, many space applications such as "nozzle ramps" or "heat exchangers" require very thin (< 1 mm) structures whereas turbine blades would require very thick parts ($\geq$ 1 cm). Little ~~has been investigated as to~~ is known about the effect of thickness on stress-strain behavior or the elevated temperature tensile properties controlled by oxidation diffusion. In this study, composites consisting of woven Hi-Nicalon™ fibers a carbon interphase and CVI SiC matrix were fabricated with different numbers of plies and thicknesses. The effect of thickness on matrix crack formation, matrix crack growth and diffusion kinetics will be discussed.

In another approach, hybrid fiber-lay up concepts have been utilized to "alloy" desirable properties of different fiber-types for mechanical properties, thermal stress management, and oxidation resistance. Such an approach has potential for the C_f-SiC and SiC_f-SiC composite systems. CVI SiC matrix composites with different stacking sequences of woven C fiber (T300) layers and woven SiC fiber (Hi-Nicalon™) layers were fabricated. The results will be compared to standard C fiber reinforced CVI SiC matrix and Hi-Nicalon reinforced CVI SiC matrix composites. In addition, shear properties of these composites at different temperatures will also be presented. Other design and implementation issues will be discussed along with advantages and benefits of using these materials for various components in high temperature applications.

Advanced Ceramic Matrix Composites with Multifunctional and Hybrid Structures

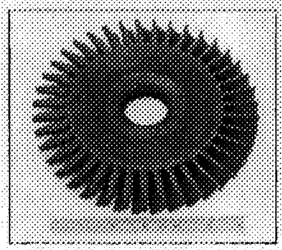
M. Singh
QSS Group, Inc.
NASA Glenn Research Center
Cleveland, OH 44135

Gregory N. Morscher
Ohio Aerospace Institute
NASA Glenn Research Center
Cleveland, OH 44135

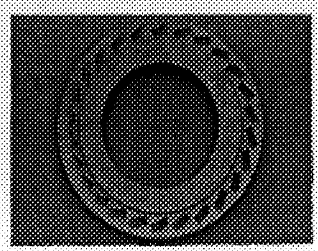
Outline

- Introduction and Background
- Needs for CMCs with Hybrid Structures
- Advantages
- Experimental
  - Composite Lay-ups and CVI
  - Elastic Modulii Measurements
  - Stress Rupture Testing
  - Microstructural Characterization (Optical, SEM)
- Results and Discussion
  - Thermomechanical Behavior
  - Microstructural Analysis
- Summary and Conclusions

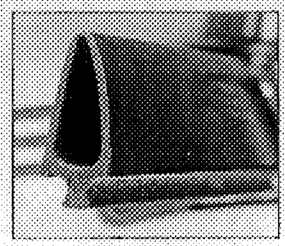
Ceramic Matrix Composites Components for Aerospace Systems



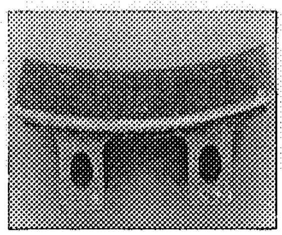
Turbine Rotor



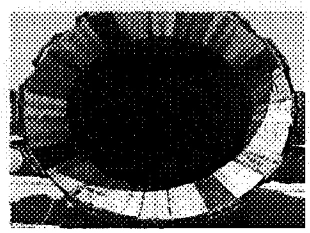
Turbopump Stator



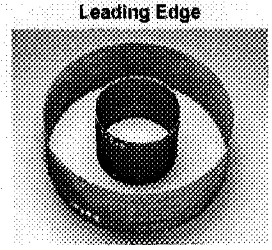
Turbine Rear Frame Leading Edge



Interstage Shroud

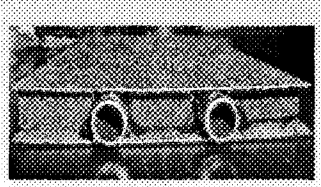


Nozzle Flaps and Seals

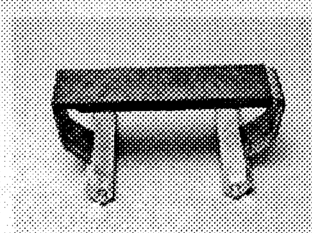


Combustor Liner

Need of Ceramic Composites with Varying Thickness and Hybrid Structures

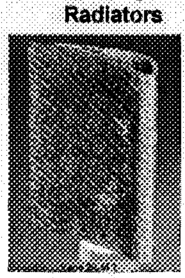


Advanced Composites for Radiators

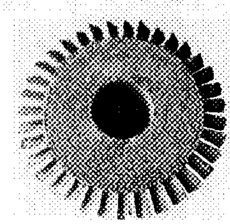


Cooled Panels for Nozzle Ramps

Composites with varying thickness and architecture are needed

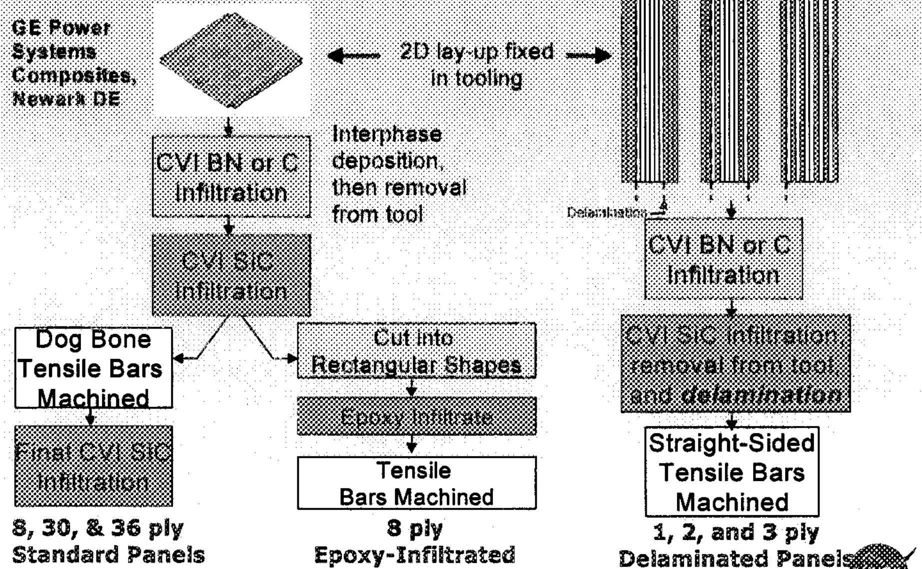


Composite Vane for Aeroengine



Composite Blisks

Approaches to Composite Fabrication



Glenn Research Center at Lewis Field

Composites with Hybrid Lay-up

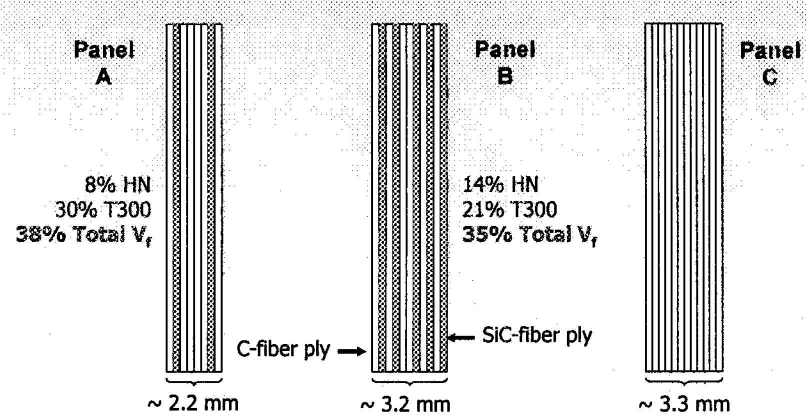
Glenn Research Center at Lewis Field

Potential Benefits of Hybrid Lay-Up in Ceramic Matrix Composites

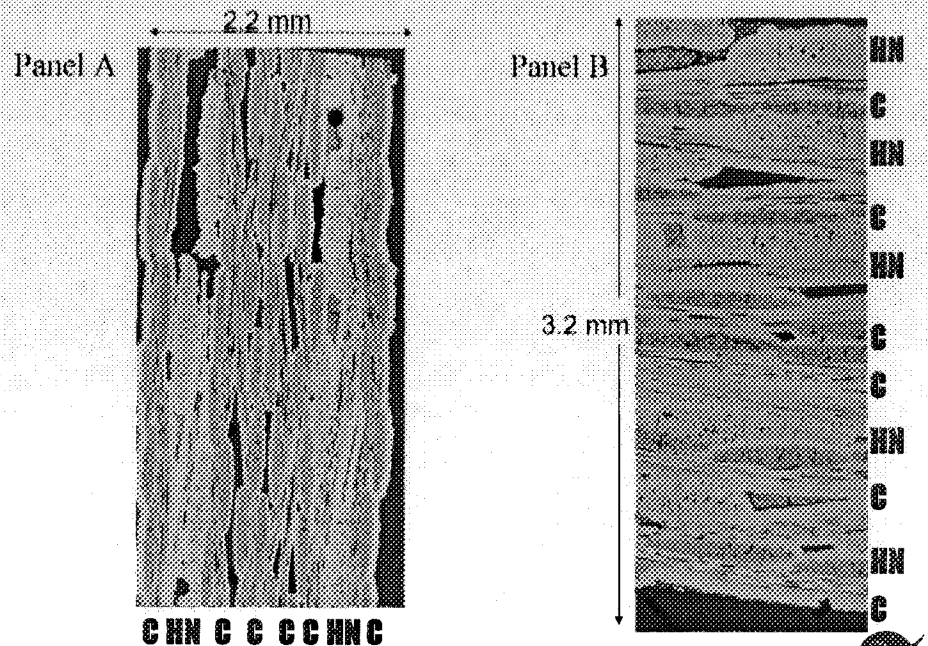
- Vary plies (fiber-types) to manipulate residual stress and matrix cracking
- Create "oxidation fire-walls" to slow down oxidation of C-fibers
- Can manipulate ply sequence for thermal-degradation (e.g., > SiC fibers on cold side and > C fibers on hot side) or residual stress-management

Tested Panels of Hybrid C/SiC Fiber CVI SiC Composites

- 20 "EPM" dogbone specimens for each (12.6 mm in grip; 10 mm in gage)
- ½ the dogbone specimens seal-coated with SiC and the other ½ seal-coated with CBS coating
- RT tensile with acoustic emission and elevated temperature stress-rupture tests were performed in air

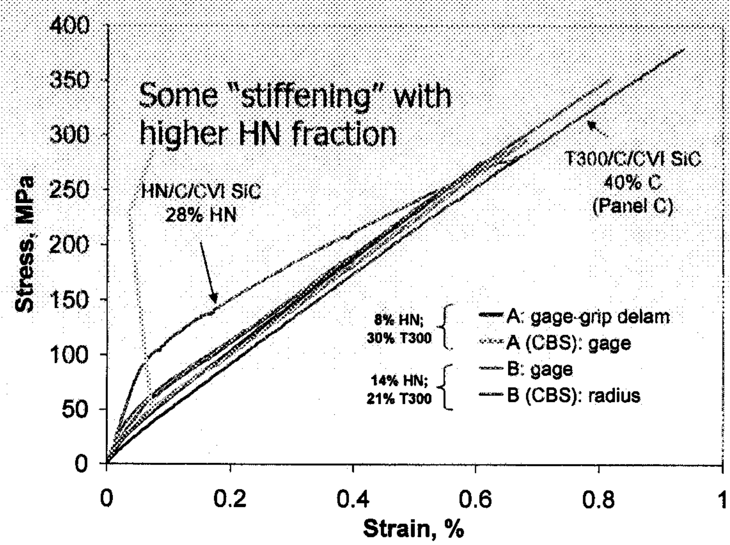


Glenn Research Center at Lewis Field



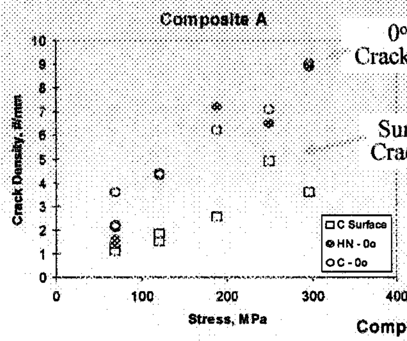
Glenn Research Center at Lewis Field

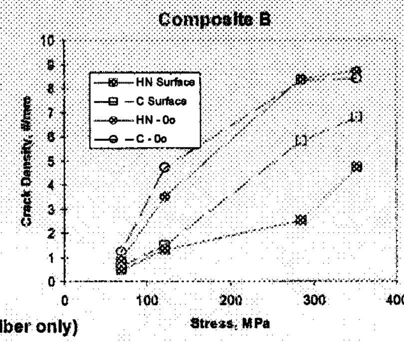
Room Temperature Tensile Behavior of Hybrid C/SiC Fiber CVI SiC Composites

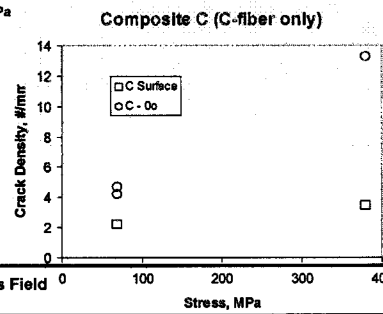


Glenn Research Center at Lewis Field

Matrix Cracking in Hybrid C/SiC Fiber CVI SiC Composites







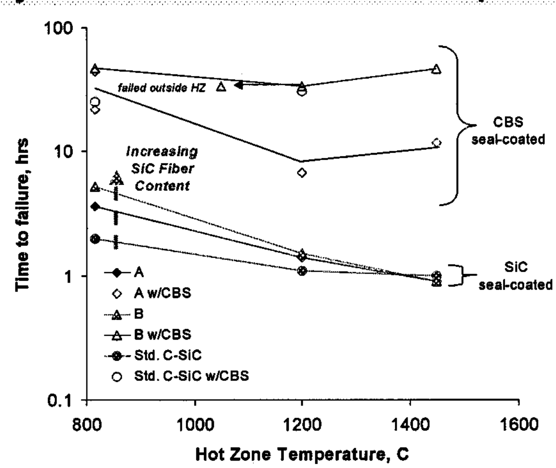
Matrix cracks counted over 10 mm length on surface and along 0° bundles on interior

Matrix cracking increases with stress similarly whether in C plies or HN plies

Glenn Research Center at Lewis Field

High Temperature Stress-Rupture Behavior in Air for Hybrid C/SiC Fiber CVI SiC Composites

Temperature Dependence for 69 MPa Rupture in Air



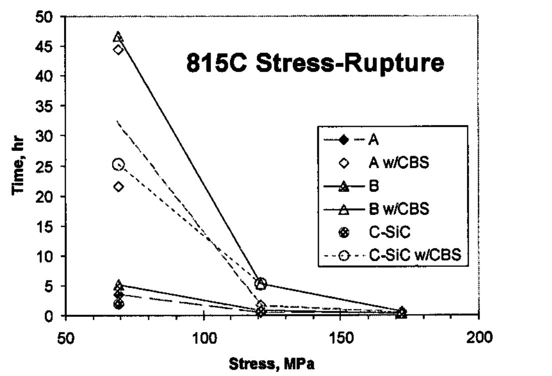
CBS coating provides best benefit at low stresses – no discernable difference for different fiber contents

Some benefit with more HN fibers for specimens not coated with CBS at low T

Glenn Research Center at Lewis Field

High Temperature Stress-Rupture Behavior in Air for Hybrid C/SiC Fiber CVI SiC Composites

Stress Dependence for 815°C Rupture in Air



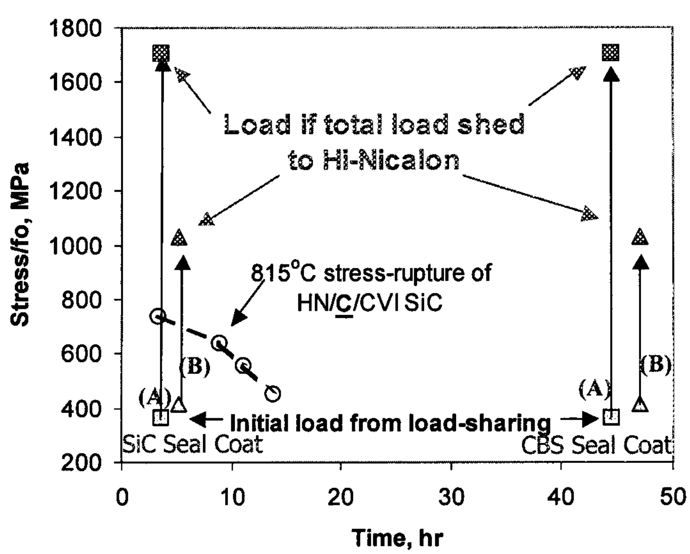
CBS coating provides best benefit at low stresses – no discernable difference for different fiber contents

at low σ

Some benefit with more HN fibers for specimens not coated with CBS

Glenn Research Center at Lewis Field

Increased loading of HN in C+HN/SiC due to oxidation of C fibers will be too great to significantly prolong rupture life in air

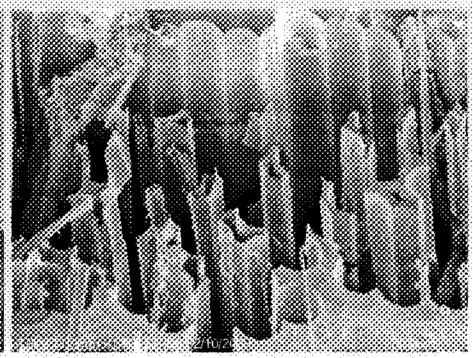


Glenn Res

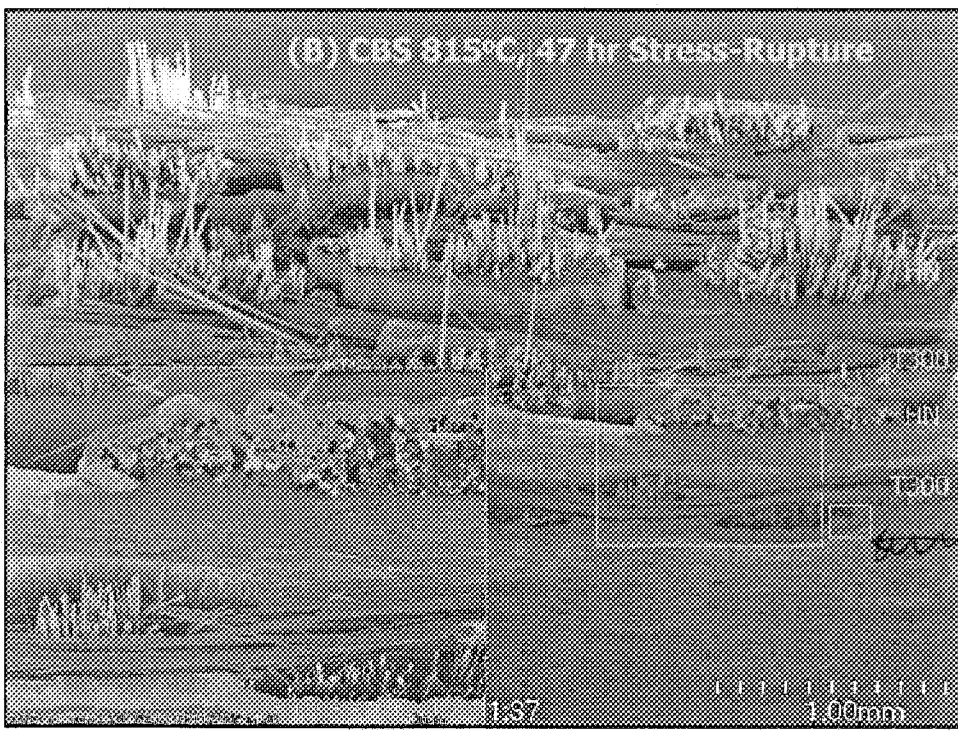
Typical Fiber Fracture Surfaces (HN) or Lack Thereof (T300)

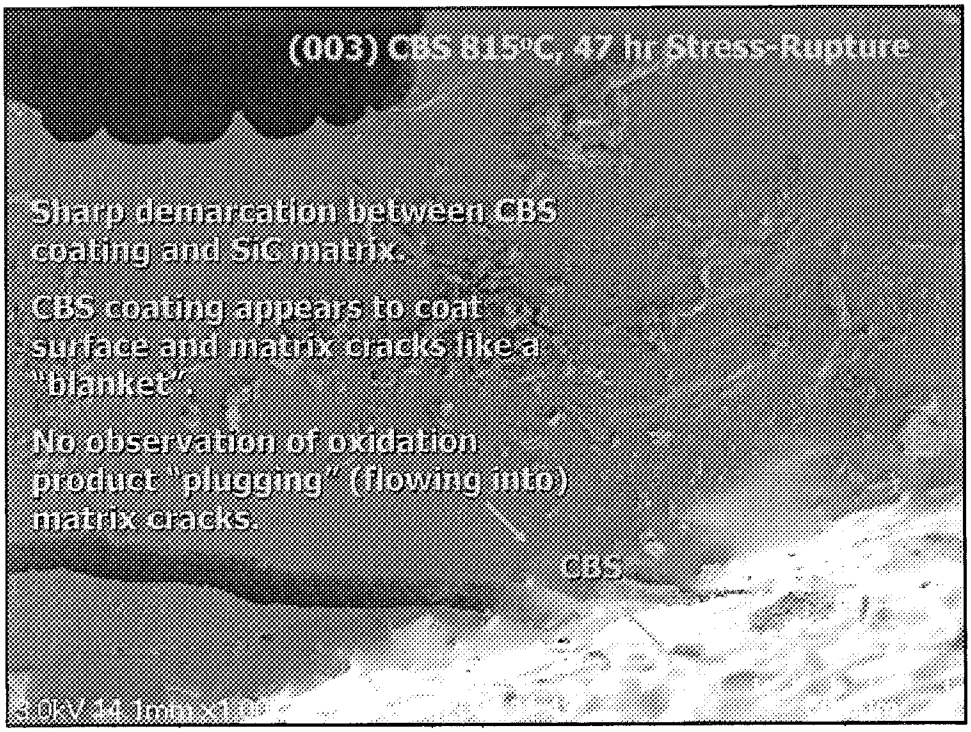
(A) SiC Seal-coat; 815°C 3.6 hr Stress-Rupture

Hi-Nicalon



T 300 Carbon





Composites with Hybrid Lay-up

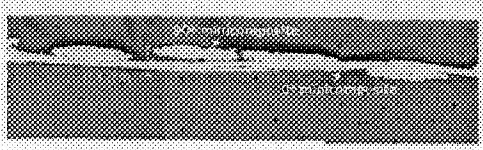
Summary and Conclusions

- Composite plates with alternating C and HiNicalon fiber plies could be fabricated with some delamination – probably better suited for tube-shaped structures
- HN plies do increase stiffness; however, this is mostly due to higher modulus of HiNicalon
  - *Matrix cracking occurred at low stresses for all of the C fiber-containing composites*
- Minor intermediate temperature stress-rupture improvement observed for HiNicalon containing composites
- CBS coating significantly improves stress-rupture life at low stresses, regardless of C and HiNicalon content

Glenn Research Center at Lewis Field

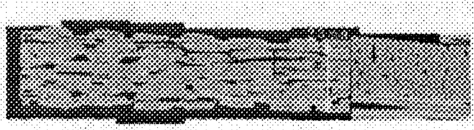
Effect of Composite Thickness on Thermomechanical Behavior

Microstructure of Hi Nicalon SiC-CVI SiC Composites



1 Ply Longitudinal Section

3 Ply Longitudinal Section



8 Ply (BN1) Cross-Section

E8Ply-8HS(BN) Longitudinal Section

30 Ply Longitudinal Section

Physical Properties of Composite Specimens

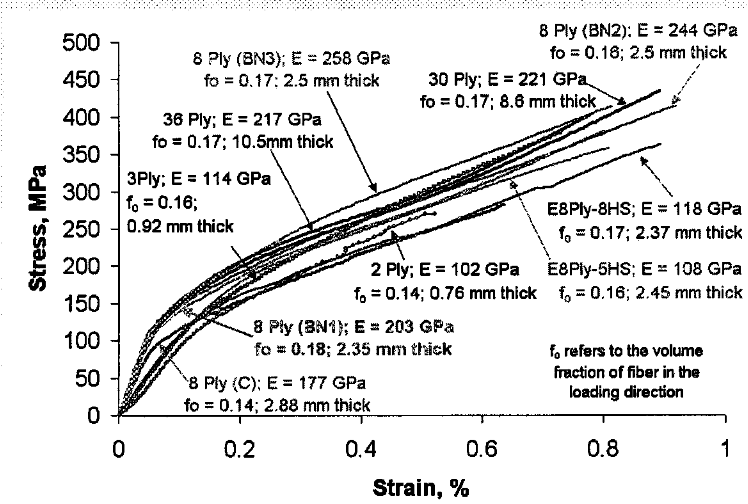
Specimen	Weave	Specimen shape	t, mm	f_f	f_i	f_{SiC}	f_p
Standard 8 Ply Panels							
8 Ply (C)	8HS	dog-A[a]	2.92	0.28	0.13	0.44	0.15
8 Ply (BN1)	8HS	dog-A	2.35	0.35	0.05	0.39	0.21
8 Ply (BN2)	5HS	dog-B[b]	2.50	0.31	0.06	0.48	0.15
8 Ply (BN3)	5HS	dog-B	2.38	0.33	0.05	0.47	0.15
Standard Thick Panels							
30 Ply (C)	5HS	dog-B	8.60	0.34	0.04	0.45	0.17
36 Ply (C)	5HS	dog-B	10.50	0.34	0.04	0.43	0.19
Delaminated Thin Panels							
1 Ply (C)	5HS	Straight[c]	0.38	0.26	0.04	0.29	0.41
2 Ply (C)	5HS	Straight	0.73	0.28	0.04	0.33	0.35
3 Ply (C)	5HS	Straight	0.92	0.32	0.04	0.35	0.29
Epoxy Infiltrated Panels							
E8Ply-5HS(BN1)	5HS	dog-B	2.45	0.32	0.05	0.25	0.38
E8Ply-5HS(BN2)	5HS	dog-B	2.45	0.32	0.05	0.27	0.35
E8Ply-8HS(BN)	8HS	dog-B	2.37	0.33	0.05	0.29	0.33

a Dogbone tensile specimen 203 mm in length, approximately 15.5 mm in width at grip section and 10.3 mm in width at gage section

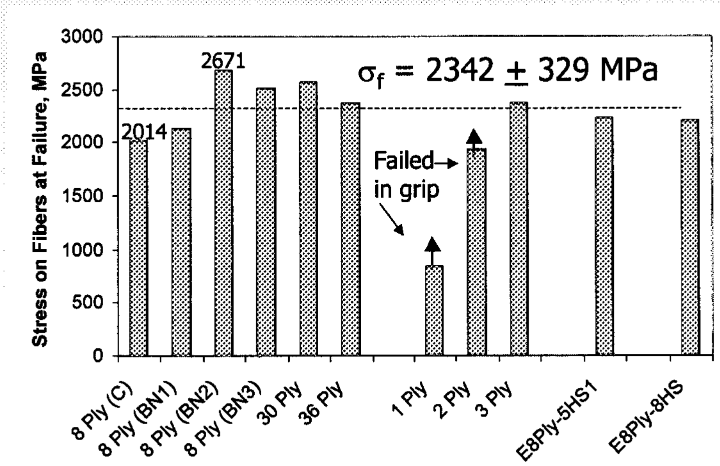
b Dogbone tensile specimen 152 mm in length, approximately 12.6 mm in width at grip section and 10.3 mm in width at gage section

s Straight-sided tensile specimen152 mm in length and approximately 12.6 mm in width throughout.

Tensile Stress-Strain Behavior of Different HiNicalon-CVI SiC Composites

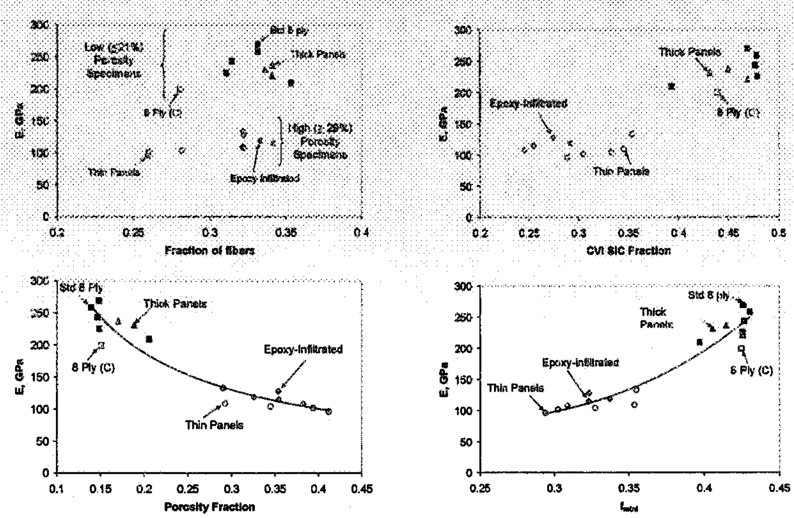


Stress on Fibers at Failure for Different CVI SiC Composite Specimens



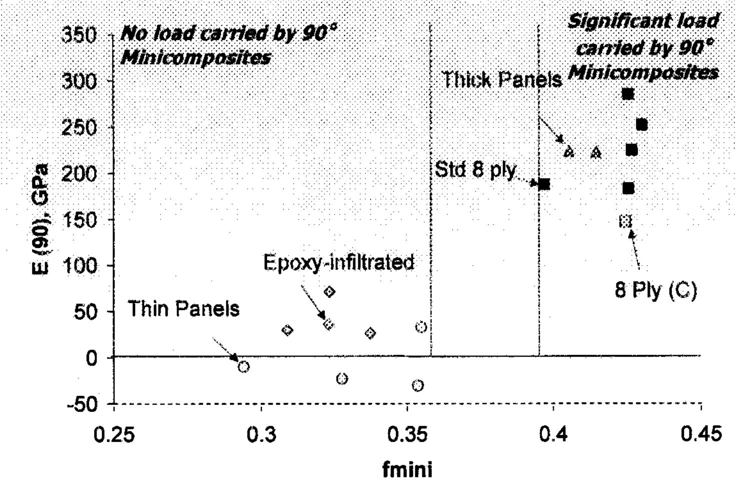
Glenn Research Center at Lewis Field

Effect of Various Physical Properties on Elastic Modulus of Composites



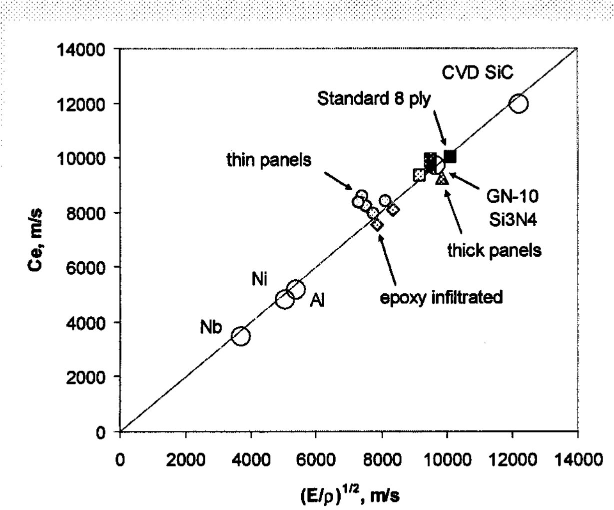
Glenn Research Center at Lewis Field

Effective Elastic Modulus of the 90° Minicomposites



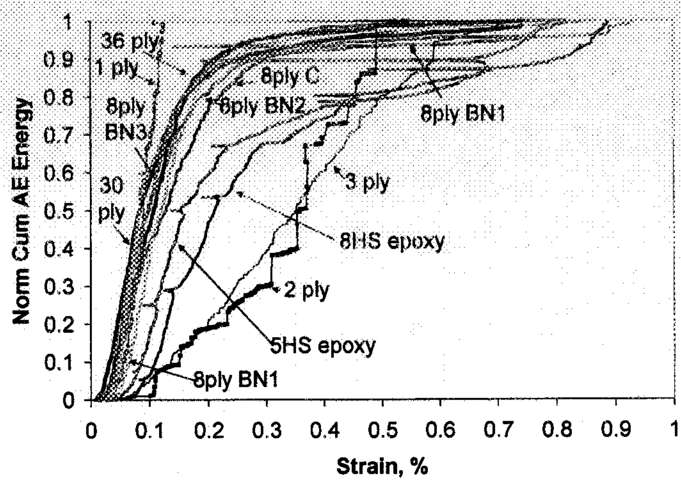
Glenn Research Center at Lewis Field

Measured Speed of Sound versus Measured $(E/\rho)^{1/2}$



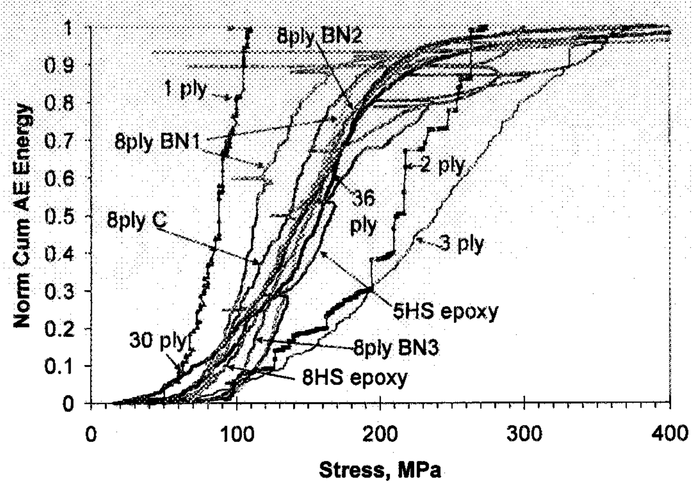
Glenn Research Center at Lewis Field

Normalized Cumulative AE Energy versus Strain



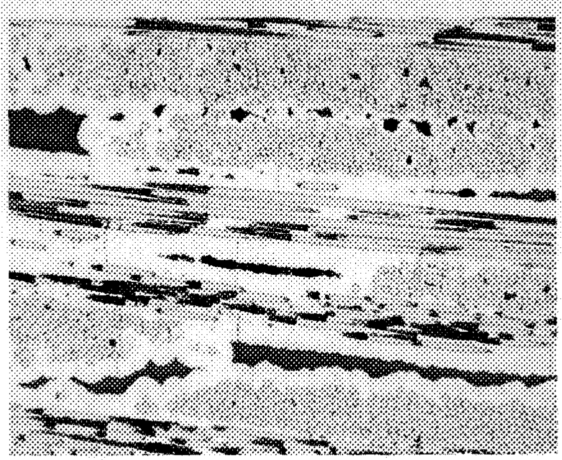
Glenn Research Center at Lewis Field

Normalized Cumulative AE Energy versus Stress



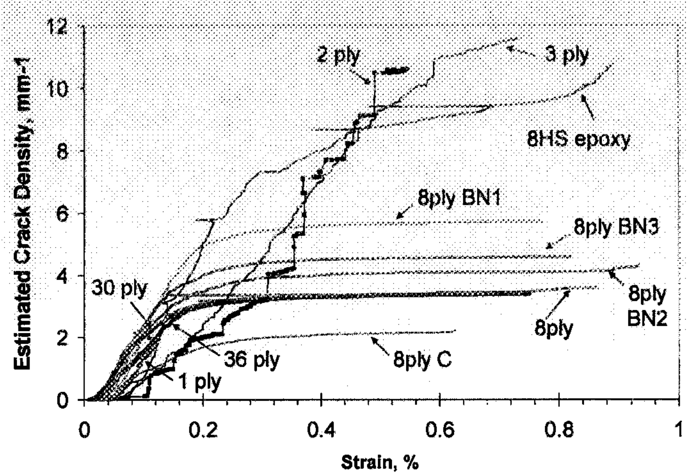
Glenn Research Center at Lewis Field

Polished Longitudinal Section Showing Matrix Cracks in 8ply BN3



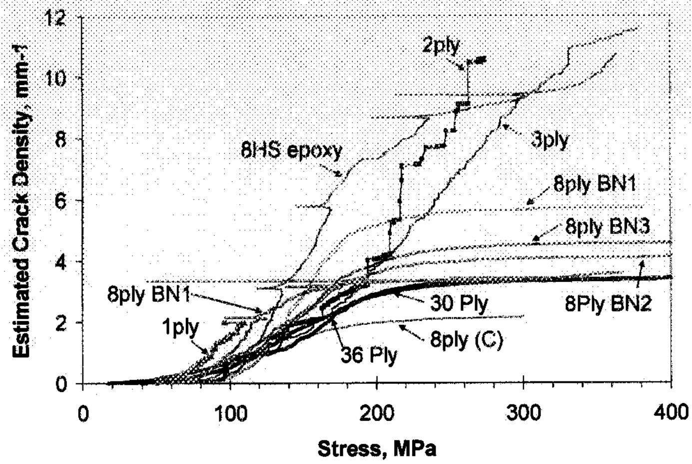
Glenn Research Center at Lewis Field

Estimated Crack Density versus Strain



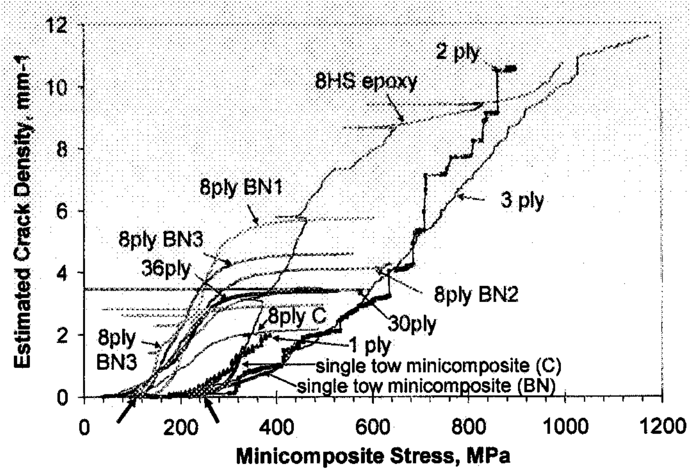
Glenn Research Center at Lewis Field

Estimated Crack Density versus Stress



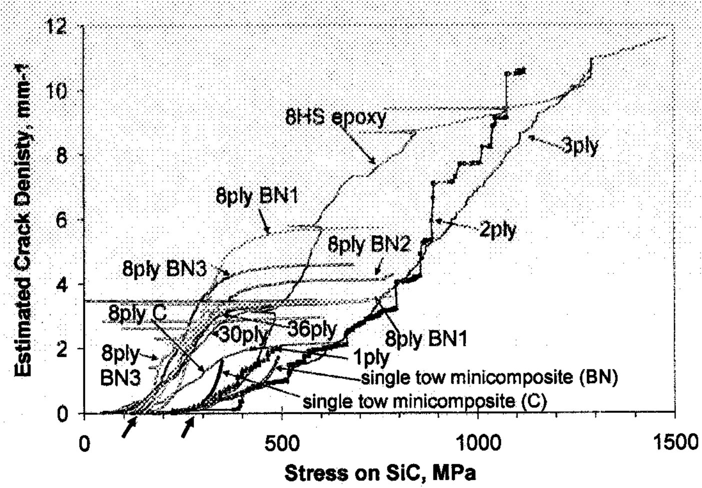
Glenn Research Center at Lewis Field

Estimated Crack Density versus Stress on Load-Bearing Minicomposites



Glenn Research Center at Lewis Field

Estimated Crack Density versus Stress on SiC



Glenn Research Center at Lewis Field

Effect of Composite Thickness
Summary and Conclusions

- The effect of constituent content on elastic modulus and matrix cracking behavior not only depends on the relative amounts of constituents, but also on the effectiveness of the structure, i.e., 90° minicomposites, to carry load.
- Lower density composites have very little load-carrying contribution from 90° minicomposites when loaded in the 0° direction.
- Higher density composites were affected by 90° minicomposites as low-stress flaw sources, whereas the matrix cracking behavior of low density 2D woven composites were not and behave very much like single tow minicomposites as opposed to high density 2D woven composites.

Glenn Research Center at Lewis Field

Acknowledgments

- Marc Freedman, NASA Glenn Research Center
- Dr. R.T. Bhatt, US Army, Vehicles Directorate, NASA Glenn Research Center
- Ron Phillips and Richard F. Dacek, QSS Group, Inc.